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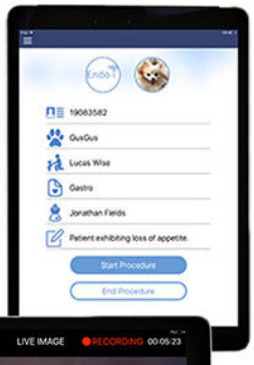

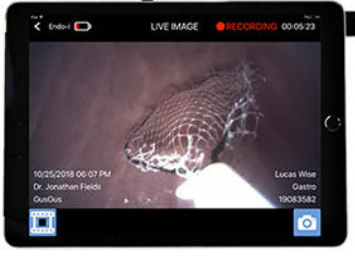

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Holter Monitoring in Clinically Healthy Cavalier King Charles Spaniels, Wire-Haired Dachshunds, and Cairn Terriers

C.E. Rasmussen, S. Vesterholm, T.P. Ludvigsen, J. Häggström, H.D. Pedersen, S.G. Moesgaard, and L.H. Olsen

Background: Few reported studies describe normal values from 24-hour ECG (Holter) recordings of small breed dogs.

Objectives: To investigate influence of breed, age, sex, body weight, degree of recording artifact, and mitral valve prolapse (MVP) on Holter recordings of 3 breeds of small dogs that have differing predispositions for myxomatous mitral valve disease. The study also assessed if heart rate (HR) at clinical examination (HRex) was associated with HR during Holter monitoring and evaluated the reproducibility of Holter variables.

Animals: Fifty clinically healthy, privately owned dogs of the breeds Cavalier King Charles Spaniel (CKCS), Wire-haired Dachshund (wD), or Cairn Terrier (CT).

Methods: Prospective, longitudinal observational study. Dogs were recruited for clinical examination, echocardiography, and Holter monitoring. In 8 CKCS, Holter recordings were performed twice with a 7-day interval. Arrhythmia and heart rate variability (HRV) analysis (time and frequency domain analysis) were performed on Holter recordings.

Results: Fifteen out of 27 Holter derived variables were significantly associated with breed ($P < .03$), but not with age ($P > .7$), sex ($P > .2$), body weight ($P > .7$), degree of recording artifact ($P > .4$), or MVP ($P > .6$). During Holter recording, minimum ($P = .0001$) and mean HR ($P = .0001$) were higher in CKCS compared with wD. CKCS had significantly lower values than wD, CT, or both in 10 out of 13 HRV variables ($P < .03$). Minimum and mean HR during Holter recording were correlated with HRex ($r = 0.55$, $P = .0003$). HR and time domain variables had a coefficient of variation $<10\%$.

Conclusions and Clinical Importance: There is an influence of breed on Holter-derived variables in 3 breeds of small dogs. Arrhythmia and HRV analysis can be performed on 24-hour ambulatory ECG (Holter) recordings. Arrhythmia analysis includes HR measurements and identification of arrhythmias.

Key words: Arrhythmias; Canine; Heart rate variability; Myxomatous mitral valve disease.

The heart rate variability (HRV) analysis is a beat-to-beat analysis that mirrors influence of the autonomic nervous system on heart rhythm, presence of arrhythmia, or both. HRV analysis can be divided into a time and a frequency domain analysis and both analyses are based on measuring intervals between adjacent sinus QRS complexes.[1] In the frequency domain analysis, the high frequency (HF) band is influenced by respiration and known to reflect parasympathetic modulation of heart rate (HR). The low frequency (LF) band is influenced by both parasympathetic and sympathetic activity.[2–4] Breed differences in variables from Holter recordings have been documented in dogs of large and medium breed.[5] In addition, breed differences are found in the vasovagal tonus index (VVTI), which is a measurement of HRV on short-time ECG.[6] Moreover, increased HRV has been found in people and dogs with mitral valve prolapse (MVP).[7–10] MVP is an early sign of myxomatous mitral valve disease (MMVD), which is the most common cardiac disease in dogs.[11,12] Small dogs are most likely to develop MMVD, and some breeds are more likely to develop MMVD than

Abbreviations:

APC	atrial premature complexes
AV	atrioventricular
bpm	beats per minute
CKCS	Cavalier King Charles Spaniel
CT	Cairn Terrier
CV	coefficient of variation
HF	high frequency
HFn	normalized high frequency
Holter	24-hour ECG
HR	heart rate
HRV	heart rate variability
LF	low frequency
LFn	normalized low frequency
MMVD	myxomatous mitral valve disease
MVP	mitral valve prolapse
N	QRS complex of sinus or supraventricular origin
SVT	supraventricular tachycardia
TI	triangular index
TP	total power
ULF	ultra low frequency
VLF	very low frequency
VPC	ventricular premature complexes
VVTI	vasovagal tonus index
wD	wire-haired standard size Dachshund

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others.[12] The Cavalier King Charles Spaniel (CKCS) is at high risk for developing MMVD, whereas the Dachshund is at moderate risk[12–14] and Cairn Terriers (CT) are at low risk.[12,13] It is suggested that HRV changes in relation to MMVD severity are caused by autonomic dysfunction as a part of the complex pathophysiology of the disease.[9,10] The aim of this study was to investigate influence of breed, age, sex, body weight, degree of recording artifact, and MVP on Holter recordings of breeds of small dogs with different predisposition for developing MMVD. The study also assessed if HR at clinical examination was associated with HR during Holter monitoring. Furthermore, the study evaluated reproducibility of arrhythmia and HRV variables.

Materials and Methods

Study Population

This prospective study included privately owned dogs of 3 different breeds: CKCS, Wire-haired standard size Dachshund (wD), and CT. Dogs were examined between December 2008 and June 2009. Only nonpregnant, nonlactating dogs between 2 and 9 years old were included. Dogs were not receiving systemic medication or had abnormal heart sounds. Dogs were included in the study only if their echocardiographic examination showed no or minimal mitral regurgitation (mitral regurgitant jet $< 20\%$ of the left atrial area).[15] Dogs were excluded if they had signs of systemic disease on history, clinical examination, serum biochemistry, or CBC. Furthermore, dogs with $<$20-hour readable data on the Holter recording were excluded. All owners gave their consent. The study was approved by the Danish Animal Welfare Division.

Examination Procedure

All dogs were examined by a standardized protocol that included blood sampling, physical examination, cardiac auscultation, and echocardiography, performed in that order. HR was estimated during cardiac auscultation. Holter recording was performed within a month after echocardiographic examination. Holter recordings were performed twice with a 7-day interval in a convenience sample of 8 CKCS.

Echocardiography

Two-dimensional echocardiography[a] was performed and recorded for later analysis by an individual masked to identify of the dog (L.H.O.). First, left ventricular dimensions were measured by use of M-mode echocardiography performed on short-axis views at the chordae tendineae level.[16] Second, the degree of MVP was evaluated in the right parasternal long axis 4-chamber view.[17] Third, a short-axis view at the level of the aortic valve was used to assess the left atrial and aortic root diameter.[18] Fourth, maximal aorta flow velocity was measured with pulsed wave Doppler in the left side 5-chamber view.[16] Finally, a color-flow mapping of the mitral- and tricuspid valve area was performed in the left caudal 4-chamber view to evaluate the degree of mitral and tricuspid regurgitatio.[15] None of the dogs were sedated during the examination and the owners were present to calm the dogs.

Holter Monitoring

A Holter recorder[b] was placed on the dog with a 2 lead system with electrodes[c] in a standard precordial placement.[19] Before electrode placement, an area was prepared by shaving and cleaning the skin with alcohol. An elastic bandage and a specially designed vest were used to secure the Holter recorder and leads to the dog. All dogs wore the Holter monitor for at least 24 hours and owners were instructed to note the general activity of the dog in a diary during the monitoring period.

HR and Arrhythmia Analysis

A standardized protocol for semiautomatic arrhythmia analyses was performed by commercially available software[d] and with the observer blinded to the identity of the dog. The software was designed for Holter recording in people; however, definition of events was adjusted for dogs (except the definition of bradycardia and "dropped beat"). The editing protocol included 2 main steps. Step 1 (chronological analysis): The Holter recordings were chronologically checked to ensure that the software triggered correctly on every beat. Step 2 (event analysis): Events marked by the software were manually checked to confirm correct classification. The software classifies QRS complexes of sinus and supraventricular origin as normal beats (N) and wide QRS as abnormal beats.[e] Bradycardia was defined as more than 4 successive N at a HR lower than 45 beats per minute (bpm). NN-intervals more than 180% longer than the previous NN-interval were defined as "dropped beats." Sinus pauses were defined as NN-intervals longer than 2.0 seconds.[20] The software registered episodes with a NN-interval 50% shorter than the previous NN-interval. These episodes were manually differentiated into atrial premature complexes (APCs) (a premature beat with abnormal P-wave morphology conducting a normal-appearing QRS complex) and "premature normals" (the remaining episodes).[10,21] The software also registered episodes where an APC or a "premature normal" was followed by 2 or more successive N at a HR above 150 bpm and with NN-intervals shorter than or equal to the previous. These episodes were manually differentiated into supraventricular tachycardia (SVT) (all beats with an abnormal P-wave morphology conducting a normal appearing QRS complex) or tachycardia (remaining episodes).[21,22] Complexes classified as abnormal by the software were manually differentiated into ventricular premature complexes (VPC), late VPC, RonT, ventricular escape beats, or fusion beats. VPCs should occur before a period similar to the previous NN-interval and were defined as wide and bizarre looking QRS complexes, not associated with a P-wave, but accompanying a large T-wave of opposite polarity.[21] Late VPC was defined as a VPC occurring within a period longer than the previous NN-interval but shorter than 2 seconds. RonT was defined as a VPC occurring before the previous T-wave returned to baseline[21] and registered based on a software defined equation.[e] Ventricular escape beats were defined as wide QRS complexes of different orientation occurring after a sinus pause.[21] A fusion beat was defined as a normal P-wave followed by an intermediate-shaped QRS complex.[23] Second-degree atrioventricular (AV) block was manually registered during the chronological analysis.[21]

HRV Analysis

HRV analysis was performed by commercially available software[f] including both time- and frequency-domain analysis. HRV analysis was carried out automatically by the software on Holter recordings already processed through the arrhythmia analysis protocol. Abnormal beats, defined by the arrhythmia analysis software, were not included in the HRV analysis. The HRV analysis was divided into 4 analysis periods: 24-hours, 6-hours inactivity, 1-hour activity, and 1-hour inactivity. The 1-hour activity period started 90 minutes before the dog went to sleep (bedtime) and the 6- and 1-hour inactivity period started 30 minutes after bedtime. The diary was used to identify bedtime for the dog. If bedtime was not noted in the diary, it was defined as the 1st period of 10 minutes after 9:00 PM with a HR below mean HR during Holter recording. Analysis periods with $<90\%$ valid NN-intervals, decided by the software, were

excluded from all statistical analyses. All 4 periods were analyzed in 1-time segment using nonaveraged power spectral density. Total power (TP) (0–0.4 Hz) was divided into the following frequency bands: ultra low frequency (ULF): 0–0.00333 Hz, very low frequency (VLF) 0.00333–0.04 Hz, LF 0.04–0.15 Hz, and HF 0.15–0.4 Hz. Gaps longer than 2.5 seconds were interpolated to sample rate (4 Hz) using a curved interpolation (Cubic Spline). Linear subtraction was used to remove constant offset or bias in the rhythm data and a Hamming window was used as algorithm to reduce frequency artifacts. The 24-hour period included 524,288 samples (178,688 zero padding). LF and HF were adjusted for TP and lower frequencies by normalizing LF and HF (LFn and HFn) by the following formula: LFn = LF/(TP−ULF−VLF)×100 and HFn = HF/(TP−ULF−VLF)×100. Besides the above-mentioned frequencies, the following HRV variables were also included in the study: HF/LF, mean of all NN-intervals (MEAN), % of successive NN-intervals differing more than 50 ms (pNN50), square root of the mean squared differences of successive NN-intervals (RMSSD), standard deviation of the NN-intervals (SD), and triangular index (TI) (total number of NN-intervals/maximum number of NN-intervals of equal length measured on a discrete scale with bins of 1/128s).[g]

Statistical Analysis

Data are expressed as mean ± standard deviation unless otherwise noted. All statistical analyses were performed with commercially available software. All shown *P*-values, except from posthoc test, were Bonferroni's adjusted. Analyses of variance were used to test arrhythmia and HRV variables for influence of breed, body weight, age, sex, degree of recording artifact, and MVP ($P < .0008$). Interactions between MVP and breed, MVP and age and in addition, breed and age were included in the statistical model if indicated by visual inspection of the distributions. Stepwise backwards elimination was used in all models until only statistically significant variables remained. Model control was performed by testing residuals for homogeneity of variation and Gaussian distribution by residual plot and Shapiro-Wilks test, respectively. Data were transformed if model control failed, and if transformed data failed the model control, data was tested separately via appropriate nonparametric tests. If a breed had a statistically significant influence on an arrhythmia or HRV variable, Students *t*-test or Wilcoxon's Signed Ranks test was used as posthoc test ($P < .05$). Spearman's correlation was used to test for association between HR at clinical examination and maximum, minimum, and mean HR during Holter recording ($P < .02$). To assess reproducibility, Wilcoxon's matched pairs test was used to test for difference in arrhythmia and HRV variables between the 2 Holter recordings from the same dog ($P < .0008$). Furthermore, reproducibility was evaluated based on coefficient of variation (CV). A CV was separately calculated for each dog (CV_{dog} = standard deviation 1–2 weeks/mean 1–2 weeks×100) and a CV for the variable was calculated as the mean CV_{dog} for the 8 dogs ($CV_{variable}$ = mean CV_{dog} 1, 2, 3, . . ., 8).

Results

Data were collected from 57 dogs: 23 CKCS, 18 wD, and 16 CT. However, 7 dogs were excluded from the study because of the presence of preexcitation (1 CT), high serum concentration of bile acids (1 CT), suspicion of Cushing's disease (1 CT), and <20 hours of readable data on the Holter recording (2 CKCS and 2 wD). The characteristics of the 50 remaining dogs (21 CKCS, 16 wD, and 13 CT) are shown in Table 1. Three CKCS and 1 wD had an innocent flow-murmur grade I. It was not possible to draw blood from 1 CT, but this dog appeared clinically healthy and all statistical analyses were statistically the same whether this dog was included or not. None of the dogs had tricuspid regurgitation.

HR and Arrhythmia Analysis

The CKCS had statistically significant higher minimum HR during Holter recording compared with wD

Table 1. Characteristics of the 50 small dogs.

	All Dogs	CKCS	wD	CT
n	50	21	16	13
Sex (M/F)	20/30	9/12	6/10	5/8
Intact dogs (M/F)	16/25	8/12	4/7	5/6
Age (years)	5.2 ± 1.8	5.1 ± 1.6	5.5 ± 2.1	5.1 ± 1.9
Body weight (kg)	9.6 ± 1.9	9.3 ± 1.7	10.2 ± 1.9	9.4 ± 2.1
HR (bpm)	107.4 ± 18.9	120.4 ± 11.7	95.0 ± 18.7*	102.4 ± 15.5*
IVSTd diff (%)	13.5 ± 16.2	16.2 ± 14.9	9.9 ± 15.4	13.8 ± 20.0
IVSTs diff (%)	11.1 ± 16.2	14.8 ± 19.4	5.9 ± 12.1	11.6 ± 13.9
LVIDd diff (%)	− 4.0 ± 9.2	− 0.5 ± 8.9	− 5.5 ± 9.0	− 7.8 ± 8.5
LVIDs diff (%)	− 1.9 ± 18.0	4.9 ± 14.6**	1.1 ± 16.8**	− 16.3 ± 17.5
LVPWd diff (%)	16.9 ± 13.6	18.2 ± 12.2	13.2 ± 14.6	19.1 ± 14.7
LVPWs diff (%)	3.9 ± 17.0	− 0.7 ± 13.5	0.1 ± 9.1	16.1 ± 23.6
FS (%)	33.7 ± 8.0	31.5 ± 6.6**	30.5 ± 7.9**	41.5 ± 9.9
LA/Ao (ratio)	1.3 ± 0.1	1.3 ± 0.1	1.3 ± 0.1	1.4 ± 0.1
Mitral valve prolapse (mm)	0.9 ± 0.7	3.2 ± 2.3**	3.3 ± 2.2**	− 0.1 ± 1.8
Max. aorta flow (m/s)	1.4 ± 0.3	1.3 ± 0.1**	1.3 ± 0.2**	1.6 ± 0.3

CKCS, Cavalier King Charles Spaniels; wD, Wirehaired Dachshunds; CT, Cairn Terriers; HR, heart rate; bpm, beats per minute; LVIDd, left ventricular end diastolic diameter; LVIDs, left ventricular end systolic diameter; LVWd, left ventricular free wall thickness in diastole; LVWs, left ventricular free wall thickness in systole; IVSTd, interventricular septal thickness in diastole; IVSTs, interventricular septal thickness in systole.

Data are expressed as mean ± standard deviation. Left ventricular dimensions are given as percentage difference from the expected dimension (diff).[24]

*$P < .05$ difference from CKCS.

**$P < .05$ difference from CT.

Table 2. Heart rate during Holter monitoring in 3 breeds of small dogs.

Breed	All Dogs ($n = 50$)	CKCS ($n = 21$)	wD ($n = 16$)	CT ($n = 13$)
Maximum HR (bpm)	181.9 ± 29.8	191.7 ± 35.9	167.4 ± 20.6	184.8 ± 22.8
Minimum HR (bpm)	46.8 ± 8.3	51.7 ± 7.5	41.8 ± 6.6*	45.3 ± 7.2*
Mean HR (bpm)	75.5 ± 12.3	82.4 ± 12.8	67.3 ± 7.5*	74.9 ± 10.3

CKCS, Cavalier King Charles Spaniels; wD, Wirehaired Dachshunds; CT, Cairn Terriers; HR, heart rate; bpm, beats per minute.
Values are expressed as mean ± standard deviation.
*Significantly lower HR compared with CKCS ($P < .015$).

and CT (Table 2). CKCS also had a statistically significantly higher mean HR compared with wD ($P = .0001$), but maximum HR was not related to breed. During the 24-hour recording period CT and wD had statistically significantly more episodes of sinus pauses than CKCS (712 ± 1,113, 551 ± 388, and 26 ± 63, respectively, all $P = .0001$). Furthermore, CT had statistically significantly more episodes of sinus pauses than wD ($P = .03$). Moreover, wD had statistically significantly more episodes of "premature normals" than CKCS (1,650 ± 1,755 versus 404 ± 471, $P = .0006$) and CT (651 ± 1,250, $P = .0009$). The occurrence of bradycardia, tachycardia, SVT, "dropped beats," 2nd-degree AV-block, APCs, VPCs, escape or fusion beats were not associated with breed, age, sex, body weigh, recording artifact, or MVP. Fifty-six percent of the dogs had 2nd-degree AV-block (all: median 1, [range 0–5,210 episodes in 24-hours], CKCS: 1 [0–139], wD: 0 [0–5,210], and CT: 66 [0–2,351]). All 2nd-degree AV-blocks had a 2 : 1 conduction ratio, except 2 CT with 1 and 8 episodes of 3 : 1 conduction, respectively. Sixteen percent of the dogs had APCs and 25% had VPCs. The numbers of APCs and VPCs are shown in Figure 1. Related to the total number of QRS complexes in the Holter recording, all dogs had <0.01 APCs and 0.02% VPCs, except 2 dogs which had 0.16 APCs and 0.16% VPCs. The majority of VPCs were single, isolated, and monomorphic. However, 1 CKCS had polymorphic VPCs, 1 CKCS had a 9 beat long ventricular bigeminy, 2 CKCS and 1 wD had <3 RonTs, and finally, <2 late VPCs were seen in 2 CKCS. None of the dogs had escape beats, except 1 wD that had 32 ventricular escape beats. Three CKCS, 2 wD, and 2 CT had <2 fusion beats.

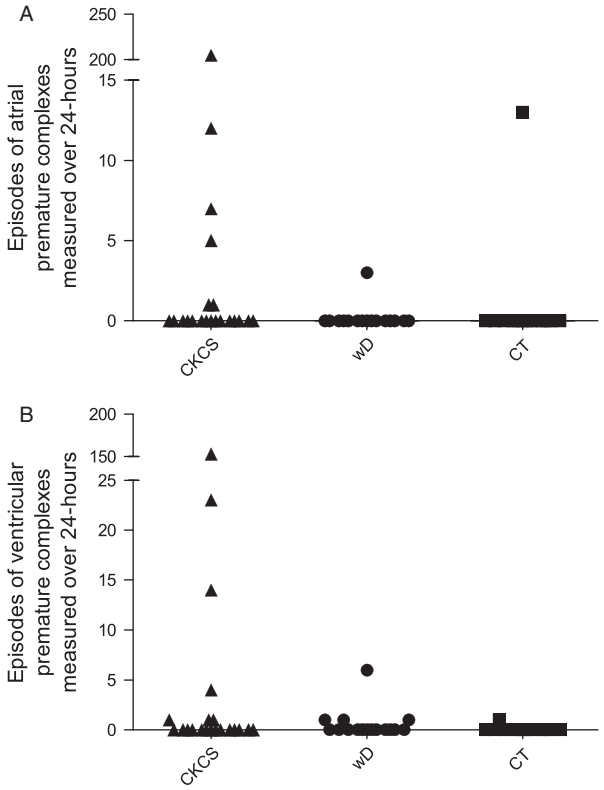

Fig 1. Graphs showing the total number of atrial premature complexes (APCs) (**A**) and ventricular premature complexes (VPCs) (**B**) during 24 hours in 21 CKCS, 16 wD, and 13 CT. There is no statistically significant difference in the occurrence of APCs or VPCs between the 3 dog breeds. Please note that the *Y*-axis is divided in 2 segments. CKCS, Cavalier King Charles Spaniels; wD, Wire-haired Dachshunds; CT, Cairn Terriers.

HRV Analysis

In the frequency and time domain analysis, CKCS had statistically significantly lower values in 10 out of 13 variables compared with wD, CT, or both (Figs 2 and 3). In the 6-hour inactivity period, breed influenced 8 out of 13 HRV variables (Figs 2 and 3). None of the frequency or time domain variables were associated with age, sex, body weight, recording artifact, or MVP.

Correlation between HR at Clinical Examination and during Holter Monitoring

Minimum and mean HR during Holter recording were positively correlated with HR at clinical examination (Fig 4), but maximum HR was not correlated with HR at clinical examination.

Reproducibility

None of the arrhythmia or HRV variables were statistically significantly different between the 2 Holter recordings from the same dog. High reproducibility was seen for maximum HR (mean CV 8%, range 2–18%), minimum HR (4, 0–13), and mean HR (4, 0.8–6) during the Holter recording. The remaining arrhythmia variables showed greater CVs: bradycardia (81, 0–141), sinus pause (115, 28–141), dropped beat (40, 9–68), "premature normals" (31, 1–60), APC (37, 0–141), tachycardia (36, 3–114), SVT (35, 0–114), and VPC (47, 0–141). None of the 8 dogs selected for studying reproducibility had escape or fusion beats. In general, time domain variables showed high reproducibility in the 24-hour analysis period (CV < 10%) (Table 3).

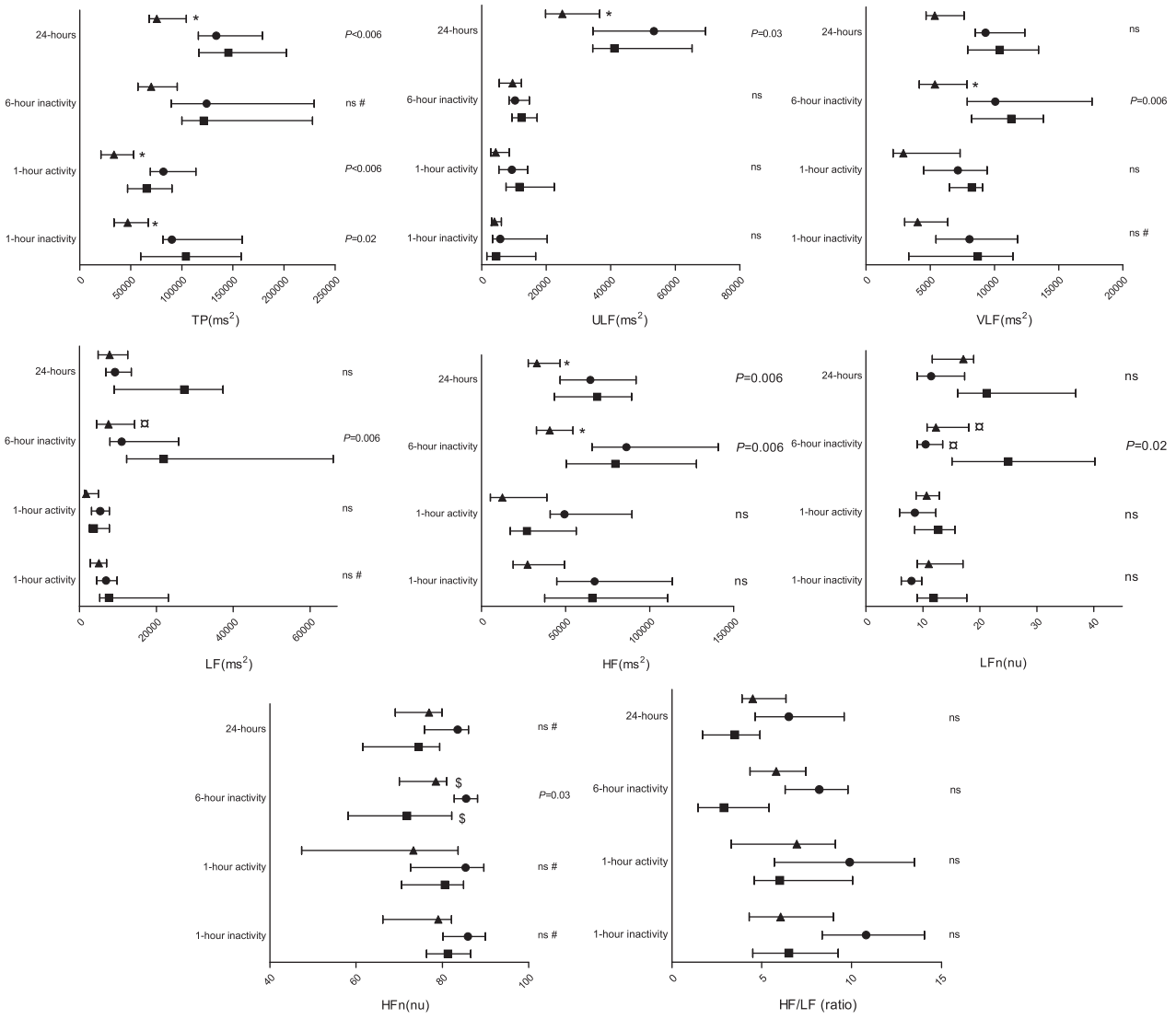

Fig 2. Graphs showing frequency domain analysis values for 3 dog breeds in 4 analysis periods. *P*-values for the statistical test of each analysis period are displayed on the right side of the graphs. The 6- and 1-hour inactivity heart rate variability (HRV) analysis period included 50 dogs, but a few dogs were excluded from the 24-hour and 1-hour activity HRV analysis periods (because of <90% valid NN-interval). Consequently, the 24-hour HRV analysis included 48 dogs (21 CKCS, 14 wD, and 13 CT) and the 1-hour activity HRV analysis included 48 dogs (21 CKCS, 15 wD, and 12 CT). Whiskers represent interquartile range and the following symbols represents median for 3 dog breeds ▲, CKCS; ●, wD; ■, CT; *, significantly lower compared with the 2 other breeds; $, significantly lower compared with wD; ¤, significantly lower compared to CT; #, data tested nonparametrically. See text for abbreviations and for definition of NN-interval, frequency domain variables, and analysis periods.

Discussion

This study showed that CKCS, compared with wD, had a higher minimum and mean HR during Holter recording and fewer episodes of "premature normals" and that CKCS had fewer episodes of sinus pauses compared with both wD and CT. CKCS had lower HRV, which was confirmed as CKCS had lower values of many HRV variables compared with those of wD and CT. However, the statistical differences between CKCS and the 2 other breeds were most apparent in the 6-hour inactivity period. Minimum and mean HR during Holter recording was moderately correlated with HR at the clinical examination. HR during Holter recording and all time domain variables in the 24-hour period showed high reproducibility (CV < 10%).

To minimize total variability this study was based on a standardized protocol, included only pure breed dogs of 3 specified breeds and echocardiographic, arrhythmia, and HRV variables were evaluated by trained observers being blinded to the identity of the dogs. All Holter recordings in this study were carefully manually edited because of the use of a Holter analysis software designed for people.

Breed differences exist in arrhythmia variables from Holter recordings of Cocker Spaniels, Boxers, and Dobermans.[5] Moreover, the short-time ECG HRV variable, VVTI are influenced by breed.[6] The present study also

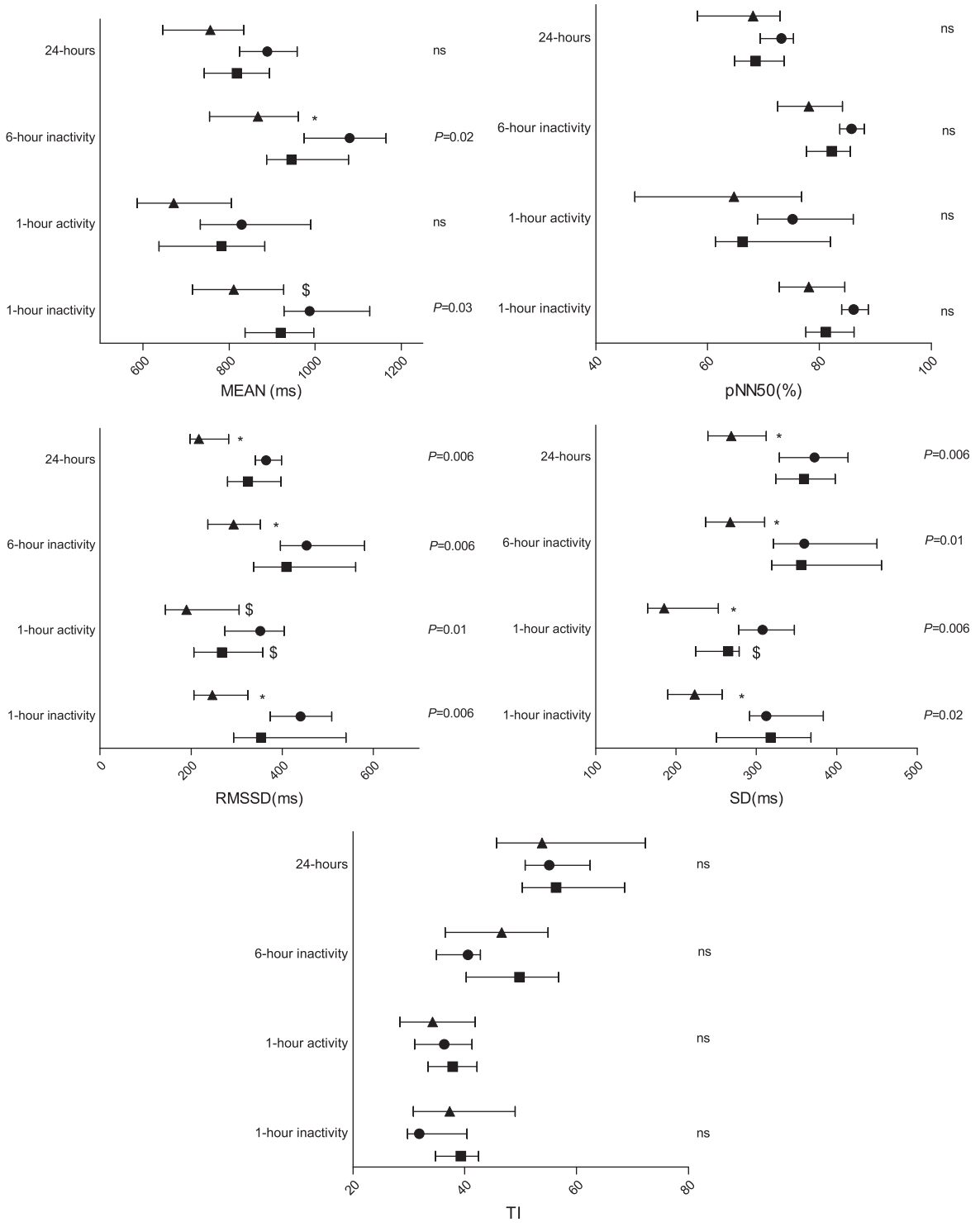

Fig 3. Graphs showing time domain analysis values for 3 dog breeds in 4 analysis periods. *P*-values for the statistical test of each analysis period are displayed on the right side of the graphs. The 6- and 1-hour inactivity heart rate variability (HRV) analysis period included 50 dogs, but a few dogs were excluded from the 24-hour and 1-hour activity HRV analysis periods (because of <90% valid NN-interval). Consequently, the 24-hour HRV analysis included 48 dogs (21 CKCS, 14 wD, and 13 CT) and the 1-hour activity HRV analysis included 48 dogs (21 CKCS, 15 wD, and 12 CT). Whiskers represent standard deviation and the following symbols represents mean for 3 dog breeds ▲, CKCS; ●, wD; ■, CT; *, significantly lower compared with the 2 other breeds; $, significantly lower compared with wD. See text for abbreviations and for definition of NN-interval, time domain variables, and analysis periods.

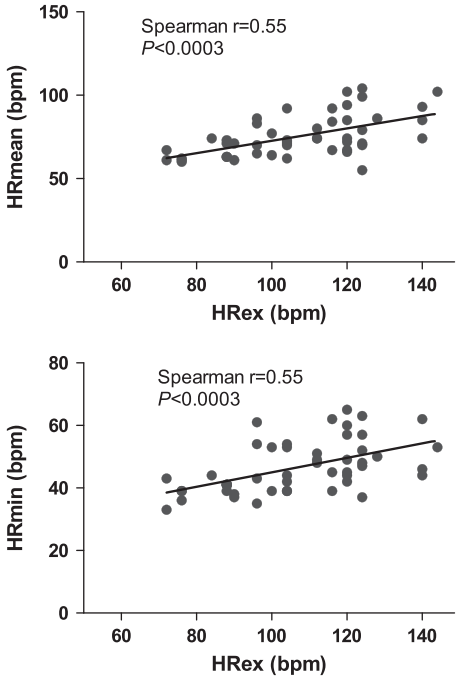

Fig 4. Correlations between heart rate at clinical examination and minimum and mean heart rate during 24-hour Holter recording. Spearman's correlation coefficient *r* and *P*-value are shown above the plot. HR, heart rate.

showed breed differences in both arrhythmia and HRV variables, which suggests that breed should be taken into account when evaluating Holter recordings. The high HR found in CKCS in this study could be associated with high sympathetic modulation of HR. However, in the HRV analysis CKCS had low LF and LFn values, which are related to low sympathetic tone.

Age, sex, and body weight have previously been associated with HRV variables in people and dogs.[3,9,25–27] However, other studies in dogs find no association between age and HRV[28] or between body weight and HR.[29] In the present study, age, sex, and body weight were not associated with arrhythmia or HRV variables. The association in people clearly demonstrates decreasing HRV with increasing age and lower HRV in women.[3,25–27]

Autonomic dysfunction is suggested to play a role in the pathophysiology of MMVD. There is a positive association between HRV and MVP in healthy dogs.[9,10] However, the present study did not detect associations between MVP and arrhythmias or HRV variables. The lack of association might be explained by the minimal degree of disease in dogs included in this study. Studies in people concerning MVP and HRV have conflicting evidence.[7,8,30]

HR measured from short-time ECG during in the clinical examination does not reliably estimate mean HR during Holter recording of dogs with heart failure and atrial fibrillation.[31] This study demonstrates a correlation

Table 3. Coefficient of variation for heart rate variability.

HRV Variables/Analysis Period	24-Hours (%)	6-Hours (%)	1-Hour Activity (%)	1-Hour Inactivity (%)
TP	17.1	26.9	15.6	36.4
	(3.2–28.6)	(6.1–67.9)	(3.1–60.2)	(4.5–68.6)
ULF	19.2	41.9	29.5	68.5
	(3.9–31.2)	(17.5–94.8)	(18.8–43.0)	(33.6–118.4)
VLF	17.2	25.6	14.3	27.8
	(3.5–25.4)	(16.3–39.4)	(1.6–32.9)	(4.4–60.1)
LF	22.3	31.0	28.1	38.0
	(0.5–59.0)	(1.0–123.8)	(2.3–47.4)	(8.0–82.1)
HF	16.8	23.5	32.1	45.6
	(1.5–38.0)	(4.1–40.2)	(5.0–105.0)	(3.5–80.9)
LFn	11.5	28.9	25.5	34.7
	(1.0–36.3)	(1.9–101.2)	(9.3–38.8)	(11.0–62.5)
HFn	4.2	8.2	26.2	12.9
	(0.8–9.8)	(0.4–27.5)	(1.2–66.0)	(0.0–29.5)
HF/LF	15.1	33.4	41.7	44.9
	(0.5–45.1)	(0.4–112.9)	(10.3–76.6)	(5.9–75.3)
MEAN	4.3	4.3	7.1	6.2
	(1.6–6.1)	(2.7–7.8)	(0.2–19.5)	(3.4–9.3)
pNN50	5.2	2.4	13.4	5.1
	(0.3–10.9)	(0.7–4.3)	(3.8–34.4)	(1.4–8.2)
RMSSD	10.0	11.3	18.1	17.3
	(2.4–18.8)	(0.2–21.2)	(3.7–42.4)	(8.6–27.4)
SD	8.7	13.5	8.5	17.3
	(0.7–17.0)	(1.4–31.7)	(0.6–25.8)	(3.8–31.8)
TI	8.6	9.2	12.5	21.5
	(1.4–14.8)	(0.3–26.5)	(5.1–22.1)	(9.1–42.0)

The table shows the coefficient of variation for HRV variables measured twice with a 7-day interval in 8 CKCS. Values are expressed as mean (min.–max.). Because a few dogs had <90% valid NN-intervals, $n = 6$ for all 4 HRV analysis periods (the excluded dogs were not the same in all analysis periods). Se text for abbreviations and for definition of NN-interval, HRV variables, and analysis periods.

between HR estimated by auscultation at clinical examination and minimum and mean HR during Holter recording. However, minimum and mean HR during Holter monitoring cannot accurately be predicted from HR at clinical examination. Spontaneous variability accounted for 80% of VPCs in a Holter study performed on Boxers with arrhythmogenic right ventricular hypertrophy.[32] Although the number of VPCs in this study is much lower, our results also suggest a large spontaneous variability of VPCs (CV 47.4%). In people with various heart diseases, the spontaneous variability of VPCs was 83%.[33] The present study and a study of healthy Dobermans showed higher reproducibility of the time domain variables than the frequency domain variables. In addition, both studies showed a higher reproducibility in the 24-hour analysis period compared with a night or inactivity period of shorter duration.[34] Studies in people have also shown high reproducibility of time domain variables measured over a 24-hour period.[26,35]

It is remarkable that CKCS, the dog breed included in this study at highest risk for developing MMVD, overall had lower HRV values compared with both wD and CT. It is also interesting that CKCS had a higher HR at clinical examination compared with wD and CT and a higher minimum and mean HR during Holter recording compared with wD. Further studies are needed to clarify if these findings and CKCS having lower HRV play a role in the pathophysiology of MMVD and are related to CKCS being predisposed for developing MMVD.

In conclusion, many HRV variables were influenced by breed, but no variables were influenced by age, sex, body weight, recording artifact, or MVP. CKCS differed most prominently from wD by having higher HR and lower HRV. HR measured at clinical examination was moderately correlated with minimum HR and mean HR during Holter monitoring. Furthermore, the study showed high reproducibility of HR and time domain variables during 24-hours Holter monitoring.

Limitations

The Holter analysis software does not mark APCs as abnormal beats and therefore APCs are included in the HRV analysis, which might have influenced the HRV variables in the study. In addition, the HRV analysis software does not include gaps longer than 2.5 seconds, which could bias ULF and VLF in dogs with longer sinus pauses. Only 8 dogs of the same breed was examined to assess reproducibility.

Footnotes

[a] Vivid I Echocardiograph, GE-Medical, Milwaukee, WI

[b] Lifecard CF Digital Holter Recorder, SPACELABS Healthcare Company (previously Delmar Reynolds), Issaquah, WA

[c] 3M Red Dot Electrodes, 3M, St Paul, MN

[d] Pathfinder digital Holter Analysis System V8.701, SPACELABS Healthcare Company (previously Delmar Reynolds)

[e] Pathfinder 700/600/500 Instruction manual ©2004. Delmar Reynolds Medical Limited, Hertford, England. Drawing No. 038/0360/0 Issue 1 CN 4340. Part no 18-6032

[f] HRV Tools Software Package Version 1.73, SPACELABS Healthcare Company (previously Delmar Reynolds)

[g] HRV Tools. Installation and instruction manual. ©2004 Delmar Reynolds Medical Limited, Hertford, England. Drawing No. 038/0369/0 Issue 2 CN 4657. Part No 18-0369

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